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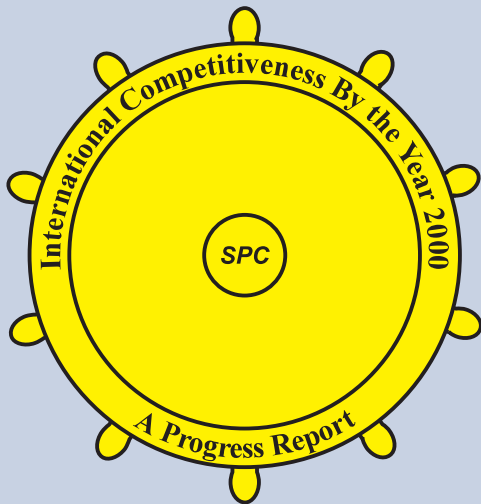
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Shipyard Operational Improvement Through Process Management

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ABSTRACT

Under the Defense Advanced Research Projects Agency (DARPA) Maritech Program, the project, titled "Process Improvement Testbed for Shipyard Construction, Conversion and Repair," is applying state-of-the-art agile manufacturing and process improvement technology to ship construction, repair, and maintenance. DARPA's Agile Manufacturing Program has sponsored the development of a prototype suite of software tools, called ProcessTOOLS, for use in modeling and managing enterprises. Other research and commercial tools exist that can perform one or more of the modeling, scheduling, enactment, and simulation functions necessary for enterprise management. ProcessTOOLS is unique, however, in that all the functions are integrated into a single package and utilize a common representation. Using ProcessTOOLS, a shipyard maintains an accurate model of its operations, utilizes advanced scheduling techniques to assign process steps to shipyard resources, manages the execution of processes according to schedule, accurately monitors the status of processes in real-time, and simulates the shipyard forward in time from its current state to assess the impacts of a contract award, to forecast the effects of changes in internal processes, and to evaluate the probable delivery date of an order. By modeling a repair or construction job prior to bidding, ProcessTOOLS facilitates more detailed planning during estimation, which results in a more realistic bid. By providing continually updated status during production, ProcessTOOLS expedites just-in-time delivery of labor, material, and equipment to the job. Event information is archived as it happens during production to form a rich source for accurately measuring performance and realistically supporting future estimates.

INTRODUCTION

After decades of depending almost entirely on Navy ship construction and ignoring many commercial ship construction opportunities, the U.S. shipbuilding industry has been in economic doldrums. The Navy's orders for new ships have declined as a result of reductions in defense spending, and construction of large commercial vessels is handled mostly by highly-competitive foreign shipyards. Only 11.5 % of the \$ 18.7 billion major U.S. shipbuilding dollars are for commercial contracts, and of that, only a fraction is for off-shore orders[1]. Past experience in other industries, such as the semiconductor and automobile industries[2], has shown that sustaining a market presence requires U.S. businesses to become commercially competitive in the global marketplace. U.S. shipyards need to increase commercial business to offset the reduction in Navy business, though international shipyards provide strong price competition, especially shipyards in the Far East and Eastern Europe. The international shipbuilding market is projected to pick up as oil tankers built in the 1970's come due to be replaced or refurbished, but U.S. shipbuilders are unaccustomed to competing in that market. The cruise shipbuilding market is also increasing, though European shipyards (Italians, Germans, Finns) have much of that business.

U.S. ship builders are being helped to attract a greater percentage of the world market. The Defense Advanced Research

Projects Agency (DARPA) Maritech Program supports advanced technology development projects that will demonstrate improved practices and processes used for the design and construction of ships in the United States, surpass international competition, and yield significantly more affordable Navy ships. The Maritech Program is sponsoring a project, titled "Process Improvement Testbed for Shipyard Construction, Conversion and Repair." The principal goal of this project is to demonstrate a prototype suite of advanced computer-aided, enterprise management technologies called ProcessTOOLS, which were developed under DARPA's Agile Manufacturing Program as an enabling technology development and demonstration project. ProcessTOOLS is deployed at a small U.S. shipyard, and it will be used to support actual ship construction and ship repair projects. Improvements in shipyard operations realized by applying the advanced technology will be measured and reported.

The names, ProcessTOOLS and ProcessBASE, are herein associated with a research prototype and one of its components, respectively, and are not to be construed as belonging to any commercially available product.

The remainder of this paper begins with the project background information, which includes the process maturity model and agile manufacturing. Then ProcessTOOLS is summarized from two viewpoints: its functional capabilities and its architecture. Finally ProcessTOOLS use by individuals at several

organizational levels in shipyard is described.

BACKGROUND

The goal of this Maritech project is to improve construction, conversion, and repair operations in a real shipyard by applying state-of-the-art process technology using ProcessTOOLS. The approach is to develop a process improvement testbed at a small shipyard in which to apply the technology. In the process improvement testbed, the plan is to model the shipyard enterprise, manage shipyard functions using the models, and then measure quantitative process improvement based on a set of developed metrics. The early focus in modeling has been on Navy ship repair, maintenance, and shipyard administrative support. By the end of the project, modeling will be extended to cover ship construction and conversion, and commercial as well as Government contracts.

Through the performance of this contract, shipyards will gain a set of re-usable resource and process models, experience in applying ProcessTOOLS to actual shipyard operations, and useful metrics for measuring performance improvement. After a brief introduction to enterprise modeling, a model for ranking process maturity is presented. Agility, as it applies to the shipyard context, and the advantages of locating the testbed at a small shipyard are presented.

ProcessTOOLS and Enterprise Modeling

ProcessTOOLS is a suite of software tools for use in modeling and managing virtual enterprises. A virtual enterprise is a dynamic alliance of cooperating organizations where the resources of each are integrated to support a particular product effort for as long as it is economically justifiable[3]. Using ProcessTOOLS, an organization can begin to manage the impact of change to its business processes by planning and simulating potential alternatives. Process changes can be tested using the ProcessTOOLS software before any changes are implemented in the organization. ProcessTOOLS also supports real-time monitoring and control across geographically distributed units.

The key to managing change in an enterprise is understanding the enterprise itself. ProcessTOOLS facilitates this understanding by providing the capability to construct enterprise models. These models consist of:

- Products or services provided within or by the enterprise;
- Processes that are executed to manufacture products or provide services;
- Resources and capabilities needed to perform process steps;
- Flows that transport objects between process steps; and
- Material inventories, tool cribs, and information repositories that are involved in the process.

ProcessTOOLS provides a suite of special purpose editors that are designed to support the construction of high-fidelity enterprise models. These models can be executed to either manage the actual operations of an enterprise, or to simulate the operations.

Process Maturity Model

In describing how to re engineer business processes,

Hansen[4] draws a sharp distinction between the traditional continuous improvement (CI) and total quality management (TQM) philosophies, and a more pragmatic approach that implements these philosophies by utilizing computer-aided analysis to manage and improve process performance. The model used to characterize the maturity of processes was originally created for software development by the Software Engineering Institute and generalized by Hansen[4] into the Process Maturity Model shown in Table I. At the higher levels of process maturity, improved productivity and quality are realized.

In shipyard operations, process maturity varies between Level 1 and Level 2. The Government requires documented Test and Inspection Plans, which enforce

Level	Characteristics	Supported by
Level 5 Optimizing	Improvements Fed Back into the Process	Modeling and Simulation
Level 4 Managed	Process Defined and Measured	Statistical Process Control Data Collection
Level 3 Defined	Process Defined with Standardized Results	Flow Charts and Process Maps
Level 2 Repeatable	Process Informally Defined with Predictable Results	Documentation
Level 1 Initial	Ad Hoc / Chaotic	CI and TQM Communications

Table I Process Maturity Model

mandatory procedures for Quality Assurance (Level 2). Although the quality inspection procedures are rigorously defined, some production processes, such as painting, which depends on the weather, are less stringent and rely on quality inspection to catch errors.

Features in ProcessTOOLS advance shipyard operations through the levels of process maturity toward the Level 5 objective. Enterprise modeling generates the documentation required at Level 2, the flow charts and process maps required at Level 3, and the simulation-capable models required at Level 5. These models also drive scheduling and enactment, and they are archived as artifacts that can be reused on identical or nearly identical processes. Simulation can test out candidate plans to help decide on the best alternative. As processes are simulated or enacted, they generate audit trails. The audit trails can be mined for the statistical process information needed to achieve Level 4 and for the actual performance data needed at Level 5 as feedback to make the models more realistic.

Navy ship repair activities can be divided into two major segments:

- Planning and Estimating, and
- Production.

The Planning and Estimating segment is triggered when the Navy issues a request for proposal (RFP). A shipyard prepares an estimate based on the job specification and submits a bid from the estimate and complex pricing considerations. The Production segment is kicked off only if a shipyard is awarded the contract. The shipyard performs the contract and delivers the repaired ship. Project schedules and costs are recorded during the performance of the contract, but not much of this is used in preparing subsequent bids. The bidding process relies heavily on the experience of senior shipyard management.

The method for evolving ship repair processes to maturity Level 5 is shown in Figure 1. For repair operations, the strategy is to close the estimate-to-production loop by feeding back the actual labor/material cost and schedule to compare to the original basis of estimate. This results in a more accurate basis of future estimates, better cost control, and predictability.

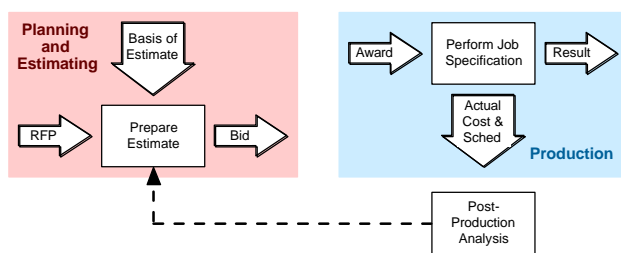


Figure 1 Feeding Back Actuals from Production

Agility

In a manufacturing sense, agility is a comprehensive response to the business challenges of profiting from rapidly changing, continually fragmenting, global markets for high-quality, high-performance, customer-configured goods and services[3]. Agility, applied to business practice, has been brought on by today's broader product ranges, shorter model lifetimes, ability to process orders in arbitrary lot sizes, and ability to treat masses of customers as individuals. Agility is replacing the less profitable mass-production system in the most technologically advanced societies. To be agile, a company must be capable of operating profitably in a competitive environment of continually, and unpredictably, changing customer opportunities.

In an agile company, management must move away from centralized power and authority and share responsibility for the success of a company with the other employees. This necessitates adjusting the available resources on a running basis, monitoring progress toward goals in response to personnel performance, evolving opportunities, and changing parameters of marketplace success. ProcessTOOLS enables agile forecasting forward in time under a variety of "what-if" scenarios for strategic and tactical planning purposes. ProcessTOOLS facilitates agile operations by providing real-time status monitoring of ongoing work, rescheduling activities in response to unpredictable changes, and allowing workers at all levels of an enterprise to simultaneously view all of the information relevant to their tasks.

A goal in managing shipyard operations is to locate the right people, the required equipment, and the necessary material in the right place at the right time. This reduces or eliminates many of

the problems that contribute to cost overruns and loss of productivity. Excessive costs arise when:

- There is an oversupply or under supply of labor;
- Labor with the proper trade certification is unavailable;
- Equipment either is not available or is available, but not operational;
- Material arrives too early and must be inventoried; or
- Material arrives too late and delays a job.

ProcessTOOLS can be used to plan, schedule, monitor, re-plan, and reschedule shipyard tasks in real-time. The availability of labor and equipment can be scheduled to avoid costly surprises. Material purchases can be planned to synchronize with project schedules in order to avoid costs associated with early and late deliveries.

Testbed Site Selection

Locating the testbed at a relatively small shipyard is best. Introducing changes in direction or focus is much easier in a small shipyard. Equipping a small shipyard with computers is a much lower capital expense than it is for a larger shipyard. In a small shipyard, the chain of command has fewer layers, and all employees have direct knowledge of many facets of the company's operations. Finally at a small shipyard, an individual employee is expected to perform multiple responsibilities and authorities without disrupting operations.

Expected Benefits

ProcessTOOLS provides detailed production schedules by clearly defining processes and sub-processes. This identifies all components of actual work to be accomplished and the order in which it is performed. ProcessTOOLS assigns tasks to resources, defines goals for workers, and allows a manager to view the scheduled tasks and processes in real-time. With the ability to view all scheduled task and resource assignments, management understands the ramifications of changes and is guided in predicting the outcome of alternative scenarios. Customers are informed by up-to-the-minute contract status information. Workforce predictions become more accurate, which minimizes unscheduled work time or over-manning. The reduction of ephemeral paper reports through interaction with real-time information is a large benefit to the shipyard and their customers.

PROCESSTOOLS OVERVIEW

This section describes the current functionality and architecture of ProcessTOOLS.

ProcessTOOLS Functionality

The relevant functional capabilities of ProcessTOOLS are: modeling, scheduling, simulation, forecasting, enactment, and analysis.

Enterprise Modeling. ProcessTOOLS modeling capability is designed with novice users in mind, providing simple, easy-to-understand interfaces. Specialized editors have been implemented to make model building as straightforward as possible. The user is able to focus on the model, rather than the details of the tool.

Scheduling. In most organizations, scheduling resources to perform process steps is an important task. In organizations that produce small lots of special orders, scheduling becomes a critical procedure, and efficient scheduling is necessary to minimize work-in-progress. ProcessTOOLS supports an advanced scheduling package that can use a variety of algorithms, such as “just-in-time” or “soonest,” to assign resources to process steps at particular times. Table II identifies the algorithms currently available for use in the scheduling process.

generated schedule. The MANAGER component monitors the schedule and sends messages to resources when a process is due to be executed. Special distributed components called AGENTs are associated with resources. AGENTs provide interfaces to human operators, computers, and machines, and are used to display task lists and send back status messages that are used to update a real-time display. Moreover, during enactment, ProcessTOOLS automatically gathers statistics about resources and processes that can be used to tune models and update

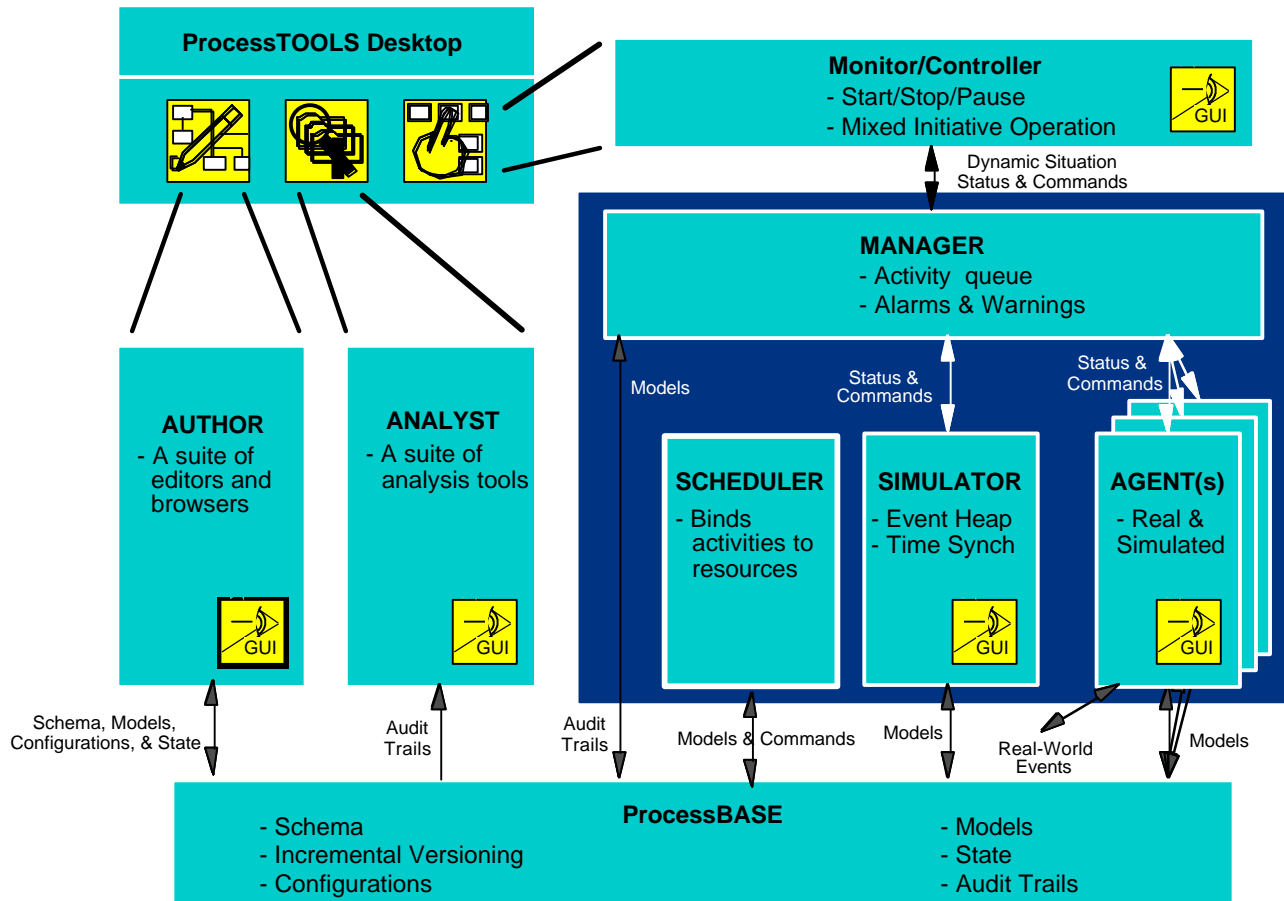


Figure 2 ProcessTOOLS Architecture

Resources are not embedded into the process description. Instead, ProcessTOOLS supports the late-binding of resources so that the assignment of particular resources to process steps can be made when the steps are scheduled.

Simulation and Forecasting. The enterprise models built using ProcessTOOLS can imitate the operation of an enterprise by running them in a discrete event simulation. Simulation can be used to determine whether a certain order can be completed with the stated delivery date or to investigate the effects of adding another resource. With ProcessTOOLS, a manager can apply the same models that are being used to enact the enterprise to run projections and answer “What-if” questions.

Enactment. ProcessTOOLS can be used to automatically manage the enactment of processes according to the

parameters for simulation.

In shipyard enactment, foremen and supervisors operate the computer on behalf of workers. AGENTs incorporate interfaces to allow them to operate as local internet applications or as World Wide Web clients, using Web browsers.

Performance Data Analysis. ProcessTOOLS generates enterprise performance data which can be evaluated for performance. Enterprise metrics are

Scheduling Algorithm	Description
Just-in-Time	Schedule all tasks to complete at latest possible date while meeting delivery time.
Slack	Schedule task starting now, ending just before the job is done.
Soonest	Schedule task starting now, and every new step to start as soon as possible.

Table II Scheduling Algorithms

measures of characteristics or performance of enterprise entities or activities. The purpose for obtaining metrics is to manage, or better manage, the enterprise. Hence, the process of collecting metrics to better manage an enterprise consists of the following steps:

- Measure enterprise performance,
- Hypothesize likely areas of enterprise performance improvement,
- Obtain more focused enterprise performance measures,
- Devise and introduce likely effective process improvements, and
- Re-measure process performance and statistically test for significance.

The above steps are repeated continuously and in a variety of contexts throughout the enterprise, given that once the greatest local process impediment is removed, another always stands in wait as the next “long pole.”

The enterprise model information view contains a number of sub-components in which metrics can be readily gathered (due to the electronic format of the contained data).

ProcessTOOLS Architecture

While research and commercial tools exist that can perform one or more of the modeling, scheduling, enactment, and simulation functions, ProcessTOOLS is unique in that all the functions are integrated into a single package and utilize a common representation. The major components of the ProcessTOOLS architecture and their interrelationships are shown in Figure 2. Depending on processing requirements, the system can be configured so that all of the components execute on one processor, or they can be distributed as required across a network of processors. Individual components are described in more detail below.

AUTHOR. A critical component of enterprise modeling is the capability to model processes. The AUTHOR component contains a graphical programming language for modeling processes. Processes can be modeled as collections of steps connected by links representing sequencing, and flow/control constructs representing conditionals, loops, and other composites. The diagrams are constructed using a drag-and-drop interface, and modeling is guided by special editors associated with each construct.

Monitor/Controller. Using the Monitor/Controller, a manager can detect at a glance the status of active processes within

an organization. Figure 3 shows what a manager may see using Monitor/Controller.

The display contains boxes that represent process steps, arranged in chronological order according to the current schedule. The dotted vertical line near the middle of the display is the now line - boxes to the left of the now line have completed execution, while those to the right have yet to start. The boxes are color coded according to task status. A box can be selected and expanded in an additional display to provide more detail.

MANAGER. MANAGER is a dispatcher that

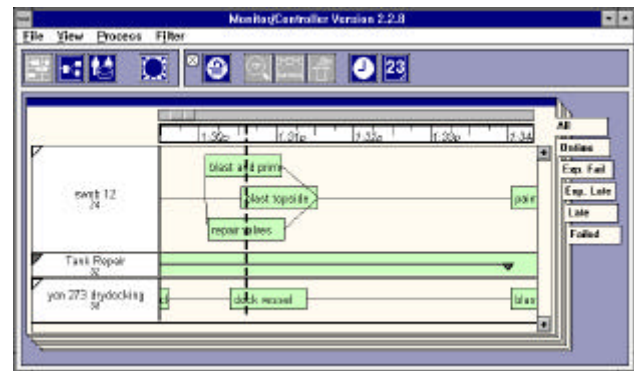


Figure 3 Monitor/Controller View

controls enactment or simulation, and it records data for all events. This provides a project manager, shop superintendent or foreman a review of the current job task list. By using MANAGER, the foreman is notified continually of worker tasks and has the ability to assign workers to a task. The foreman provides status changes to AGENTS like task start, pause, continuation, various required task inputs (values, conditions), and task completion (successful or unsuccessful, with optional explanations).

SCHEDULER. SCHEDULER is a scheduling algorithm that assigns a start time and finish time to each process step based on precedence order. Additionally, SCHEDULER dynamically binds resources to each process step by matching the process step's requirements to the resources' capabilities.

SIMULATOR. SIMULATOR is a generator of simulated events that substitute for enacted events. A simulated statistical variation generates confidence in completing work as scheduled. Also it provides an estimate of future manpower utilization, task durations, and job cost. The simulation allows “What-if” explorations, such as the effects of changing subcontractor mark-up cost, using shift labor, and procuring equipment. Simulation accountability is based on past performance or equipment failure rate and repair times. The shipyard can use these results to increase bid accuracy, or schedule to mitigate performance risks.

AGENTS. AGENTS are a distributed, web-based computer interface to human operators. This interface shows a worker's list of scheduled tasks when a worker pulls up the day's assigned tasks.. Figure 4 shows what a user would view on an agent interface.

ProcessBASE. ProcessBASE is an object-oriented, persistent data facility which stores all transactions for later use. AUTHOR uses ProcessBASE to store models; MANAGER stores the audit trail structures required by ANALYST for analysis.

ANALYST. Using the process and resource

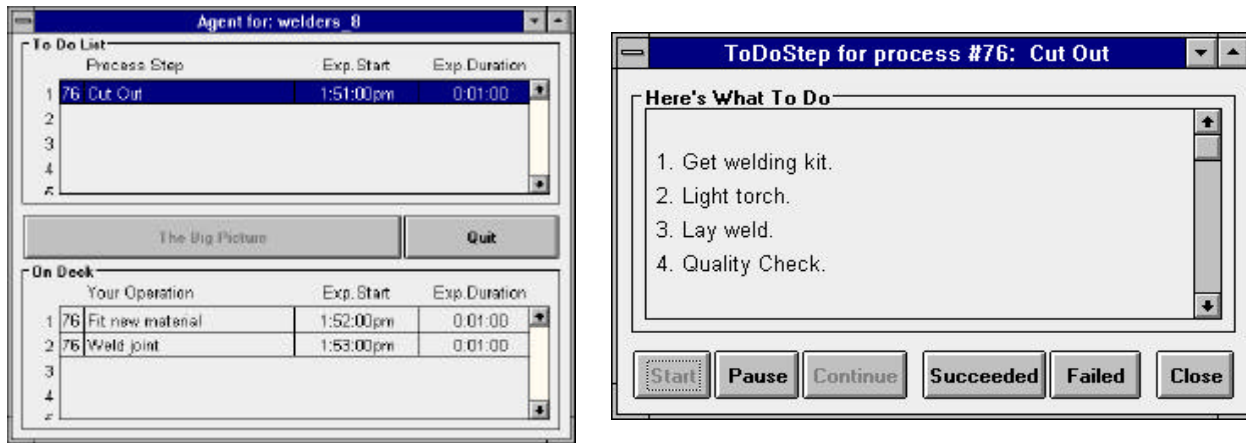


Figure 4 Agent View

models to enact or simulate an organization's business provides a wealth of information, which is archived by MANAGER in audit trails. MANAGER collects statistics (e.g., actual start and end times, actual cost, and actual resource assignments) for each process and process step. This information forms the basis for the performance analysis of actual operations computed and displayed by ANALYST. and actual resource assignments) for each process and process step. This information forms the basis for the performance analysis of actual operations computed and displayed by ANALYST.

USERS IN A SHIPYARD ORGANIZATION

ProcessTOOLS is targeted for use by many different people fulfilling roles at all levels of a shipyard organization. The abstract shipyard organization of Figure 5 is not that of any specific shipyard, but it is intended to provide the context for illustrating the use of ProcessTOOLS in performing various tasks. This section describes typical users and shows how they would use the ProcessTOOLS suite as a job flows from bid, through performance, to contract completion. The target users include the CEO/general manager, project manager, superintendent/foreman, and quality assurance manager.

CEO/General Manager

The CEO and general manager are responsible for bid/no-bid decisions, management of the in-flow of new work, and oversight of current jobs. Such individuals use ProcessTOOLS to model and simulate the shipyard's ability to profitably perform a particular job mix on time when constrained by available resources. New work arrives for consideration in the form of a Request for Proposal (RFP), Supplemental Agreement (shipyard initiated change to contract), or Change Order (customer

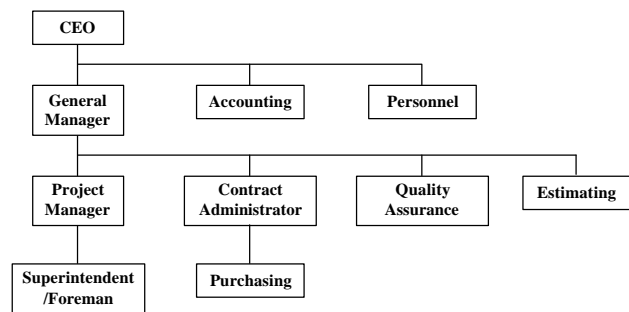


Figure 5 Typical Shipyard Organization

initiated change to contract), with work specifications, including start and completion dates. New work is modeled, which includes the process steps to be performed and the capabilities required to perform them. The model is run (starting at the time of the proposed new work) in a simulation with process models of current production jobs and anticipated available resources to forecast the completion date and provide a level of confidence in that date. Confidence in the completion date is strengthened and the plan is improved by "what-if" simulation of the impacts of adding or removing resources, subcontracting work vs. bringing work in-house, and other trade-offs. The benefits to the CEO and general manager are:

- Confidence in meeting job requirements under a variety of circumstances,
- Labor and material estimates for contract performance, and
- A tentative job schedule before the bid is submitted.

Project Manager

The project manager is directly responsible for a specific project, seeing that all of the work is completed according to specification and scheduled delivery dates and within budget. Once a job is bid and won, the project manager adopts the job model, which was created during the bidding process, as the baseline for performance. The new job model is scheduled with the current job mix and shipyard state, and a simulation is rerun to confirm milestone date feasibility. Then the new job model is enacted with the current job mix to join the real-time model of

shipyard operations. The ProcessTOOLS Monitor/Controller is the project manager's primary interface for viewing real-time project status via several views. The color-coded Gantt view is used in viewing the schedule status and sequence of tasks. The resource view shows the tasks mapped to each resource over time, and the author view shows all of the process diagram's conditionals and branches. The project manager can inspect a task's scheduled start, scheduled duration, actual start, actual duration, and assigned resource. The Monitor/Controller interface can be customized extensively to filter out unwanted items and only show the items of most interest, e.g., the off-schedule tasks appearing yellow or red in the Gantt view, depending on severity. The project manager can use ProcessTOOLS as a decision aid by taking a snapshot of the current state and running simulations based on alternative corrective action to be taken. These simulations provide new delivery dates and confidence measures, which the project manager can use in making decisions on which alternative corrective action to take. Tasks can be rescheduled using different objectives (slack, just-in-time, etc.) and resources can be added or subtracted (including subcontractors). ProcessTOOLS also provides up-to-the-minute status for customer inquiries. The benefits to the project manager are:

- Capability to re-plan under changing and unanticipated circumstances,
- Ability to test and compare alternative plans by simulation,
- Sustained confidence in on-time completion,
- Maintained labor and material estimates to complete the contract, and
- A continually updated job schedule.

Superintendent/Foreman

The superintendents and foremen are those individuals who directly oversee the performance of trade-specific production tasks, lead groups of tradespeople (e.g., welders, sandblast/painters, machinists, and riggers), and report to the project managers. During enactment, tradespeople are given instructions via "To-Do" and "On-Deck" task lists. Responsible superintendents and foremen provide real-time status on behalf of the tradespeople they represent by notifying ProcessTOOLS when tasks start, complete, pause, continue, and fail. Tasks are completed either successfully or unsuccessfully (with an available explanation facility). In addition to tracking tasks in real-time, superintendents and foremen also may use the modeling and simulation capabilities of ProcessTOOLS to support operational decision making, but the focus is shifted to a specific trade across all projects at a lower operational level than a project manager. Status of multiple projects is reviewed at the task level from multiple perspectives:

- Schedule status and task sequence with the Gantt view,
- Resource assignment with resource view; and
- Task control flow with the author view.

In response to performance problems, a task can be assigned another resource or rescheduling can be recommended. The benefits to superintendents and foremen are:

- More accurate labor and material estimates to complete assigned tasks,
- Better forecast labor requirements,
- Rapid distribution of task synchronization and status, and
- Reduced status reporting.

Quality Assurance Manager

The quality assurance (QA) manager is responsible for the compliance of quality standards for all work performed at a shipyard. The authoring capability of ProcessTOOLS enables the QA manager to review process diagrams for control requirements, which can include required process control procedures (PCPs), training requirements, and certification requirements. This maintains confidence that the proper procedures are being utilized. During enactment, the QA manager reviews processes for proper sequence and resource assignments as well as monitoring and maintaining worker qualifications. The QA manager is able to establish a predictability in end product quality and increase accuracy of performance records through greater control of the processes. The benefits to the quality assurance manager are:

- Confidence that the proper procedures are being used,
- Accountability for accomplished work,
- Greater predictability of end product quality through greater process control, and
- Increased accuracy of performance records.

SUMMARY

The Maritech Program supports advanced technology development projects that will demonstrate improved practices and processes used for the design and construction of ships in the United States, surpass international competition, and yield significantly more affordable Navy ships. DARPA's Agile Manufacturing Program has sponsored the development of a prototype suite of software tools, called ProcessTOOLS, for use in modeling and managing enterprises. Using ProcessTOOLS, a shipyard can maintain an accurate model of its operations, utilize advanced scheduling techniques to assign process steps to shipyard resources, manage the execution of processes according to schedule, accurately monitor the status of processes in real-time, and simulate the shipyard forward in time from its current state to assess the impacts of a contract award, to forecast the effects of changes in internal processes, and to evaluate the probable delivery date of an order. By modeling a repair or construction job prior to bidding, ProcessTOOLS facilitates more detailed planning during estimation, which results in a more realistic bid. By providing continually updated status during production, ProcessTOOLS expedites timely delivery of labor, material, and equipment to the job when it's actually needed. Event information is archived as it happens during production to form a rich source for accurately measuring performance and realistically supporting future estimates.

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